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Description

Method and apparatus for controlling the transition between normal operation and overrun fuel cut-off operation of an Otto engine which is operated with direct fuel injection

The invention takes as its starting point a method or an apparatus as per the preamble of the respective claims 1 and 10, whereby the transition between normal operation and overrun fuel cut-off operation can be controlled in an Otto engine which is operated with direct fuel injection. When switching over from the normal operation to the overrun fuel cut-off operation, there is inevitably a torque jump which can cause an irregular running of the Otto engine or an unwanted judder of the vehicle. The advantages which per se derive from the overrun fuel cut-off, such as a reduction in the fuel consumption, improved braking effect of the engine and lower noise emissions, for example, must be obtained at the expense of a degradation in driving comfort. The same problem arises when, after the overrun fuel cut-off operation, the normal driving operation of the vehicle must be resumed and the Otto engine must again generate a desired torque and deliver it to the vehicle.

Various measures have already been proposed for reducing this undesirable or acceptable torque jump which is caused by the cut-off of the fuel injection in the overrun operation. The transition was not controlled in older engines, for example, i.e. the fuel injection was simply stopped in the overrun fuel cut-off operation.

A known and relatively effective measure for counteracting the torque jump during the transition to the overrun fuel cut-off is to adjust the ignition angle significantly in the direction

of ignition retard, such that the combustion of the fuel-air mixture in the cylinder of the Otto engine is still reliably guaranteed. In this case, the fuel continues to be injected during the intake phase until the switchover into the overrun operation. This results in a reduced torque, since the fuel-air mixture can no longer develop its full power in the retarded ignition phase. In many cases, however, this reduction is not sufficient to achieve a gentle transition to the overrun fuel cut-off.

The invention addresses the problem of producing a method and an apparatus by means of which a clearly greater reduction in the torque jump can be achieved. This problem is solved by the features in the claims 1 and 10 respectively.

In the claimed method or the apparatus for controlling the transition between normal operation and overrun fuel cut-off in an Otto engine which is operated with direct fuel injection, said method and apparatus having the characterizing features of the respective claims 1 and 10, the advantage emerges that the torque reduction is essentially greater than if solely the ignition angle is adjusted. This is because, as a result of injecting at least a partial quantity of the fuel during the compression phase, three beneficial effects are produced for curbing the torque. Firstly, the mass of air that is taken in decreases due to the reduced internal cooling in the cylinder, because part of the injected fuel quantity is injected at the time point when the valves of the cylinder are already closed (compression phase). Secondly, the efficiency of the combustion decreases because the fuel which is in the cylinder is swirled less vigorously when injection takes place in the compression phase. Finally, measurements have also shown advantageously that the smooth running of the Otto engine does not change if the ignition angle is adjusted even

further in the retard direction after the injection of fuel. Consequently, the injection angle can be adjusted even further in the retarded injection direction than would be the case in the known simple adjustment of the injection angle. It is further considered particularly advantageous that the torque jump can be reduced in a manner which is essentially more effective by means of the claimed method or by means of the apparatus, such that the advantages of the overrun fuel cut-off can be utilized without the driving comfort for the passengers of the vehicle being adversely affected by the torque jump.

The measures which are set out in the dependent claims specify advantageous developments and improvements of the method or apparatus that are specified in the respective claims 1 and 10. A method which is particularly simple to control is produced if the air mass that is taken in is first reduced and subsequently the ignition angle is decreased to a first minimal value, said value being predetermined for this operating mode, at which trouble-free combustion of the fuel-air mixture is still possible. This ensures that a reliable combustion of the fuel-air mixture is still guaranteed even in the case of these unfavorable ratios and that a certain torque portion is still generated in this type of operation.

After the minimal ignition angle has been reached, the fuel is injected into the cylinder during the compression phase when the valves are closed. This is contrary to the otherwise usual procedure, in which the fuel is injected in the intake phase, i.e. when the valves are open. In the claimed method therefore, the advantage is produced that the ignition angle can be decreased even further than would have been the case in the known ignition angle adjustment. The ignition angle can now be decreased to a second minimal value, which is lower and

applies to the multiple injection, since the fuel-air mixture in the cylinder remains combustible.

Only after the second minimal value for the ignition angle has been reached is it possible to cut off the fuel injection and switch over to overrun fuel cut-off operation.

When the vehicle is switched over from overrun fuel cut-off operation to normal operation, a check first ascertains whether it is necessary to carry out the injection. If this is the case, the fuel to be injected is deposited in the compression phase. As a result, the torque is slowly built up and an unwanted torque jump is avoided.

In order to facilitate the transition to the normal operation, the air mass to be taken in is increased and the ignition angle is adjusted in the advanced ignition direction.

Once a predetermined desired torque has been reached, it is possible to switch over to the fuel injection in the intake phase. The control procedure for the switchover is then complete.

In a development of the apparatus, the fuel can be deposited in partial quantities, e.g. in two partial quantities in the output phase and in the compression phase. Therefore it is easy to perform an adjustment to different engine variants or load states or the engine. The method is therefore universally applicable.

An exemplary embodiment of the invention is illustrated in the drawing and is explained in greater detail below.

Figure 1 shows an exemplary embodiment in the form of a

diagram for the control of the switchover from normal operation to overrun fuel cut-off operation;

Figure 2 shows a second diagram for the control of the switchover from overrun fuel cut-off operation to the normal operation;

Figure 3 shows a schematic illustration of a functional block diagram of the apparatus according to the invention;

Figure 4 shows a flow diagram which illustrates the transition from normal operation to overrun fuel cut-off operation.

The diagram in Figure 1 shows the schematic sequence of a switchover of an Otto engine, said engine being operated with direct fuel injection, from the normal operation into the overrun fuel cut-off operation. In this diagram, a time t corresponding to the angle of rotation of the crankshaft is plotted on the x-axis, while the torque and the ignition angle are plotted on the y-axis. The advance ignition f is plotted towards the top and the retarded ignition s is plotted towards the bottom. The curve DM shows the profile of the calculated torque and the curve ZW shows the profile of the current ignition angle during the switchover phase.

In the left-hand part of the diagram, the Otto engine is operated in the normal operating mode until the time point t1. According to the curve DM, the delivered torque is relatively high. Since the torque at the engine cannot be measured directly, it is usually estimated by arithmetic means with the aid of a torque model. In order to determine a current torque, various engine parameters and operating parameters are captured and entered into the torque model, e.g. a rotational

speed, a gas pedal position, a throttle valve position, the ignition angle, the injection mode, temperature, vehicle speed, etc. The torque model per se is known and therefore need not be explained in further detail.

The diagram also shows that the curve for the ignition angle ZW is positioned on advance ignition f until the time point t1. The adjustment of the ignition usually takes place by electronic means and is based on the signals of a rotational speed sensor.

The switchover phase U to the overrun fuel cut-off operation starts at the time point t1 and ends at the time point t3. The curves are illustrated in an exaggerated manner for clarity. With effect from the time point t1, the air mass in the cylinder is decreased to a minimal value by adjusting the throttle valve, and the ignition angle ZW is adjusted to a first minimal value in the retarded ignition s direction accordingly. The first minimal value for the ignition angle ZW, at which a reliable combustion of the fuel-air mixture is still guaranteed, is reached at the time point t2. As a result of this, the torque decreases in accordance with the curve DM. At the time point t2, the injection starts in the compression phase K which lasts until the time point t3. The fuel injection is not now cut off in this period t2-t3, but instead at least a partial quantity is deposited in the compression phase. The injection can be deposited in a partial quantity in the compression phase if the valves of the cylinder are closed, wherein the other partial quantity is injected in the output phase, or alternatively can be deposited entirely in one injection cycle.

The torque decreases further as a result of the injection in the compression phase, as is evident from the profile of the

curve DM. The ignition angle ZW is briefly adjusted in the advance direction and can subsequently be reduced to a second minimal value which is even lower than the first minimal value. The second minimal value for the ignition angle ZW is reached at the time point t3. The torque is now reduced to such an extent that it impossible to switch over to the overrun fuel cut-off operation without the smooth running of the Otto engine being noticeably affected. An essentially smoother transition to the overrun fuel cut-off has therefore been achieved.

If a greater torque is demanded from the engine, provision is made for switching back into normal operation. This procedure takes place in the reverse manner and is explained in greater detail below with reference to Figure 2.

The diagram in Figure 2 is constructed in accordance with the diagram in Figure 1. As shown in Figure 2, the switch back to the normal operation starts at the time point t1. This is subsequently followed by the switchover phase U until the time point t3. The injection in the compression phase K takes place between the two time points t1 and t2.

Provision is made, depending on the current operating situation, for carrying out an evaluation beforehand to determine whether an injection of fuel is required in the compression phase when switching back to the normal operation also. For example, in the case of a low rotational speed of the engine, it may be possible to omit the injection in the compression phase and instead inject immediately in the intake phase. In order to aid understanding, the case is explained below in which fuel will be injected in the compression phase K when switching back also.

In accordance with Figure 2, the ignition and the injection are cut off until the time point t1. After this, the ignition angle is adjusted in the advance direction (advanced ignition f) until the time point t2. In this compression phase between t1 and t2, the injection of fuel takes place in partial quantities or as a single pulse as described above. From the time point t2, the torque DM has increased to such an extent that it is possible to switch over to an injection in the intake phase if the valves of the cylinder are open. The ignition angle ZW is then adjusted in the advanced ignition f direction in accordance with the curve which is drawn as a broken line. From the time point t3, the torque has again increased to such an extent that the normal operation can be resumed without noticeably affecting the smooth running of the Otto engine.

Figure 3 shows a schematic illustration of an apparatus for controlling the transition between the normal operation and the overrun fuel cut-off operation in an Otto engine which is operated with direct fuel injection. The apparatus (switchover apparatus 10) has a control unit 11 which can be controlled using a corresponding software program. Furthermore, the control unit 11 is designed to include a program storage 12 and a data storage 13. The data storage 13 can store a torque model, for example, by means of which the current torque delivered by the engine can be estimated. Provision can also be made for further units, e.g. for specifying the rotational speed and the angle of rotation of the crankshaft.

Furthermore, the control unit 11 is preferably connected to corresponding sensors or regulators via a bus 19 (data and control bus), said sensors or regulators being arranged at the Otto engine. For example, provision is made for a device for capturing the angle of rotation 15, an actuator for a throttle

valve adjustment 16, a rotational speed sensor 17, one or more injection valves 18, etc. These units are normally present in any case, since they are required in any case for the control program of the engine management system.

An alternative configuration of the invention provides for the control program, which is used for controlling the transition between the normal operation and the overrun fuel cut-off operation or vice versa, to be included as a subprogram in the management system of the engine control. This advantageously avoids any use of additional hardware.

In a schematic illustration of a flow diagram, Figure 4 shows how the transition from normal operation to overrun fuel cut-off operation is controlled. In position 1 the program is started and, after decreasing the air mass in the cylinder (adjusting the throttle valve 16), the ignition angle is adjusted in the retard direction. In position 3 a query determines whether the current ignition angle is less than the predetermined minimal value for the ignition angle. If this is not the case (if n applies), the program jumps back to position 2. The ignition angle is decreased further and the query in position 3 is reinitiated.

If the ignition angle ZW is then less than the predetermined first minimal value, the program jumps forward to position 4. The fuel injection in the compression phase now begins, and therefore the ignition angle can be decreased after a short increase to the second predetermined minimal value. This causes the torque to decrease further, thereby finally achieving a smooth transition to the overrun fuel cut-off. After the switchover to the overrun fuel cut-off operation, this program routine is terminated.

The return from the overrun fuel cut-off to the normal operation fundamentally takes place in the reverse order. A check first ascertains whether, on the basis of the torque requirement, a fuel injection is actually required in the compression phase. If this is the case, at least a partial quantity of the fuel is initially deposited in the compression phase. As a result, the torque increases to the extent that it is possible to switch over to the entire injection in the intake phase. The injection can now be switched over to the normal operation, since a smooth transition is anticipated.